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(71) Applicants: **EVOTEC BIOSYSTEMS AG** [DE/DE];  
Schnackenburgallee 114, 22525 Hamburg (DE). **PFIZER LIMITED** [GB/GB]; Sandwich, Kent CT13 9NJ (GB).

(72) Inventors: **KRÄMER, Joachim**; c/o Evotec Biosystems AG, Schnackenburgallee 114, 22525 Hamburg (DE). **MANDER, Thomas**; c/o Evotec Biosystems AG, Schnackenburgallee 114, 22525 Hamburg (DE). **BETHELL, Richard**; c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB). **BENSON, Neil**; c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB). **BOYD, Helen**;

c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB). **GREENGRASS, Pam**; c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB). **KINLOCH, Ross**; c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB).

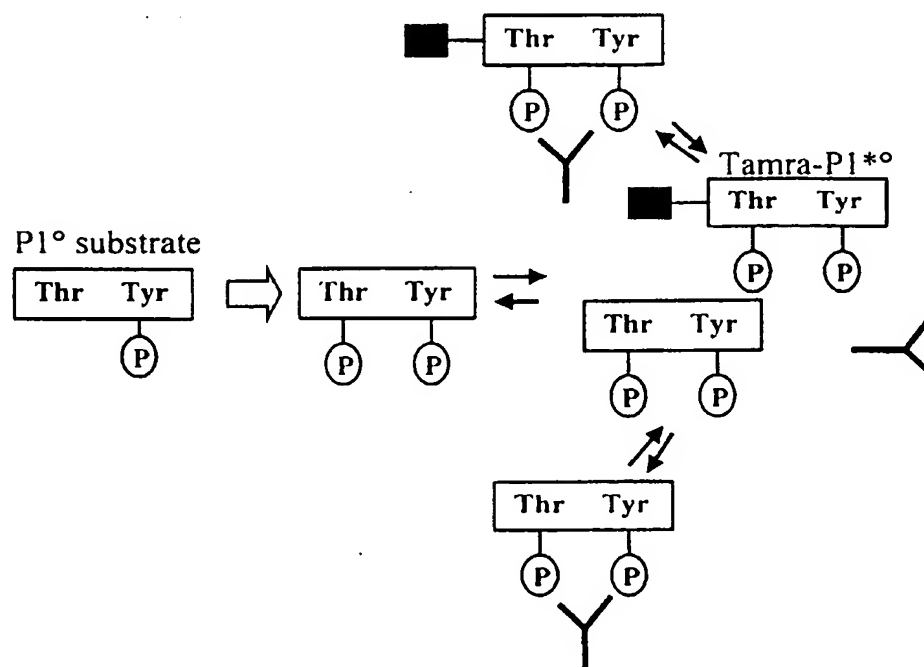
(74) Agent: **DRAUDT, Jutta**; v. Bezold & Sozien, Akademiestrasse 7, 80799 München (DE).

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[Continued on next page]

(54) Title: **PROCESS FOR DETECTING SERINE/THREONINE KINASE ACTIVITY**



(57) Abstract: The present invention describes a process for detecting threonine or serine kinase activity in an immunoassay using a pre-phosphorylated substrate.

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## PROCESS FOR DETECTING SERINE/THREONINE KINASE ACTIVITY

The present invention relates to a process for detecting threonine or serine (threonine/serine) kinase activity in an immunoassay. The invention further relates to a kit for carrying out the assay and to a preferably luminescently labelled ligand.

Protein kinases usually catalyse the transfer of the  $\gamma$ -phosphate group from ATP to a serine, threonine or tyrosine residue of an acceptor protein. These enzymes play an important role in signal transduction within cells. Detecting the activity of protein kinases would be useful for the high-throughput screening of chemical libraries. Inhibitors or activators of kinase activity, particularly low-molecular weight compounds, could eventually be developed into drugs used for the treatment of e.g. ischaemic heart disease, liver failure, diabetic neuropathies, stroke, neurodegenerative disorders including Parkinsons disease and Alzheimers disease, inflammatory diseases including asthma, rheumatoid arthritis, inflammatory bowel disease, septic shock and cancer.

It is known that mitogen-activated protein kinases (MAPK) (also referred to as stress activated protein kinases, SAPK) mediate many of the cellular effects of growth factors, cytokines and stress, leading to cell growth, differentiation and oncogenesis. MAPK/SAPK activation requires dual phosphorylation on threonine and tyrosine within the motif threonine-Xaa-tyrosine, where Xaa represents proline in the c-Jun NH<sub>2</sub>-terminal kinases (JNKs). This activation is catalysed by several MAPK-kinases (e.g. MKK4(SKK1) or MKK7 (SKK4)) which phosphorylate both the threonine and tyrosine residues of the

threonine(183)-proline-tyrosine(185) motif within the active site loop of JNK1/2/3. The MKK7 kinase has a high preference for the threonine residue whereas MKK4 preferentially phosphorylates tyrosine. This synergistic activation of JNK1/2/3 is described by Lawler S. et al in *Current Biology* 8, 1387 to 1390 (1998) and Fleming Y et al. (*Biochemical Journal*, 352, 145 - 154, 2000). Up to now the identification of an appropriate substrate which could be used to screen for specific MKK7 inhibitors is complicated by the fact that there are no synthetic substrate peptides described in the literature. The situation becomes even more critical in homogeneous assays as a potential MKK7 substrate peptide should have both a reasonable  $K_m$  for MKK7 and a high affinity for the phospho-threonine specific detection antibody in parallel. Although generic anti-phospho-tyrosine antibodies with high affinity and specificity are available for tyrosine-directed kinases (e.g. p60c-src kinase), attempts to develop generic anti-phospho-threonine/anti-phospho-serine antibodies for the same purpose have been to date less successful.

Antibodies which bind to phosphorylated threonine or serine residues with high affinity only recognize the phosphorylated amino acid in the context of the surrounding peptide sequence. For antibodies binding to JNK1/2/3 or peptide derivatives thereof, recognition is therefore dependent on two criteria: 1) MKK7-dependent phosphorylation of threonine and 2) phosphorylation of the tyrosine amino acid residue. If one of the two criteria is not fulfilled, an antibody raised against fully activated JNK1/2/3 will not specifically detect the phosphorylation site.

In *Anal. Biochem.* 255, 257 to 262 (1998) a fluorescence polarization (FP) competition immunoassay for tyrosine kinases using an appropriate substrate for this kinase is described. The kinase reaction was performed by incubation of the peptide

substrate with ATP and lymphoid T-cell protein tyrosine kinase followed by termination of the reaction with EDTA plus a fluorescein-phosphopeptide. Following the addition of an anti-phosphotyrosine antibody, the fluorescence polarization signal was measured. The phosphorylated product formed in the assay competes with the fluorescein-phosphopeptide for binding to the anti-phosphotyrosine antibody. The kinase activity results in a reduction of the FP signal and the FP signal is therefore inversely proportional to the phosphorylated product formed in the reaction.

However, such an approach for a generic assay principle for serine/threonine kinases is not realizable to date. This is because there are no anti-phospho-serine/-threonine antibodies available that bind specifically, and with high affinity, to phosphoserine or phosphothreonine residues in the absence of additional specific amino acid sequences adjacent to the phosphorylated amino acid.

It was therefore the object of the present invention to establish an assay method for detecting serine/threonine kinases or their enzymatic activity. The assay method is highly reliable and simple to perform without the need to develop specific high affinity anti-phospho-serine/-threonine antibodies.

This object has been solved by the assay process according to the features of claim 1.

As used herein, the term "kinase" refers to an enzyme capable of phosphorylating its substrate. A "serine/threonine kinase" refers to an enzyme capable of phosphorylating its substrate at a serine or threonine residue. The term "bis-phosphorylated" or "double phosphorylated" indicates that a protein or peptide comprising the sequence motif -Z-X-Y- or -Y-X-Z- is

phosphorylated both at the Z and the Y position. Unless otherwise indicated, the term "bis-phosphorylated" or "double phosphorylated" as used herein does not exclude the possibility that said protein or peptide is further phosphorylated at positions other than Y and Z.

The present invention relates to a process for detecting threonine or serine kinase activity in an immunoassay which comprises the following steps:

- a) providing a protein or peptide comprising the sequence motif

-Z-X-Y -     or     -Y-X-Z-

wherein

Z = threonine or serine

X = a sequence of preferably between 1 and 1000 amino acids which may be the same or different

Y = tyrosine, threonine or serine

as a substrate for threonine or serine kinases, said protein or peptide being pre-phosphorylated at the Y position;

- b) incubating the peptide or protein with a phosphate donor and a threonine or serine kinase to form a bis-phosphorylated protein or peptide;

- c) adding an antibody having a specificity to the peptide/protein that has been phosphorylated at threonine or serine in the Z position; and

- d) detecting the threonine or serine kinase activity.

Or to put it in other words, the invention relates to a method for determining the phosphorylating activity of an enzyme which comprises the steps of:

- a) combining said enzyme with

- a protein or peptide comprising the sequence motif

-Z-X-Y-     or     -Y-X-Z-

wherein

Z = threonine or serine

X = a sequence of preferably between 1 and 1000 amino acids which may be the same or different

Y = phosphotyrosine, phosphothreonine or phosphoserine,

said protein or peptide capable of being phosphorylated at the Z position by said enzyme;

- a phosphate donor; and
- an antibody having a specificity to a peptide/protein which is phosphorylated both at the Y and Z position; and

b) detecting the enzyme activity.

All assay components might be combined simultaneously or stepwise. The substrate might in particular be combined with said enzyme before the addition of said antibody.

Particularly, the antibody has a specificity to the bis-phosphorylated product of the kinase reaction. By detecting the presence, absence or amount of the product-antibody complex, a threonine or serine kinase activity can be measured. Or to put it in another way: the invention also allows for the determination of the phosphorylation of a substrate molecule by an enzyme at an amino acid selected from the group consisting of serine and threonine.

The present invention also relates to a kit for detecting threonine or serine kinase activity in an immunoassay which comprises the following components:

- preferably a threonine or serine kinase;
- a pre-phosphorylated substrate as defined above;
- an antibody as defined above; and
- preferably reaction buffers including a phosphate donor.

The present invention also relates to a labelled, preferably luminescently labelled, ligand for use in a serine/threonine kinase assay comprising the sequence motif



wherein

Z = threonine or serine

X = a sequence of preferably between 1 and 1000 amino acids which may be the same or different .

Y = tyrosine, threonine or serine

said protein or peptide ligand being phosphorylated at the Z and Y position.

The subclaims define preferred embodiments of the process of the present invention.

The process of the present invention as well as the kit and the labelled ligand may be used for screening for specific modulators of serine or threonine kinase activity. They are particularly suitable for screening compound libraries in order to locate molecules which inhibit or activate kinases. These molecules may be promising candidates for designing drugs used for the treatment of e.g. ischaemic heart disease, liver failure, diabetic neuropathies, stroke, neurodegenerative disorders including Parkinsons' disease and Alzheimers' disease, inflammatory diseases including asthma, rheumatoid arthritis, inflammatory bowel disease, septic shock and cancer. Screening for an agent capable of increasing or decreasing the phosphorylating activity of the enzyme typically comprises the steps of (i) performing the process as outlined above in the presence and in the absence of said agent; and (ii) comparing the activity of said enzyme in the presence of said agent with the activity of said enzyme in the absence of said agent to determine whether the phosphorylating activity of said enzyme in the presence of said agent is increased or decreased. However, the subject of the present invention might also be



useful for the study of the functionality of an enzyme. For instance, one could check whether an unknown protein belongs to the group of serine/threonine kinases or whether a specific serine/threonine kinase is biologically active.

The accompanying figures illustrate the present invention.

Abbreviations are used as follows:

P1°	H-Lys-Phe-Met-Met-Thr-Pro-pTyr-Val-Val-Thr-Arg-NH <sub>2</sub>
P1*	H-Lys-Phe-Met-Met-pThr-Pro-Tyr-Val-Val-Thr-Arg-NH <sub>2</sub>
P1*°	H-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH <sub>2</sub>
TAMRA-P1*°	5-TAMRA-AEEA-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH <sub>2</sub>
TAMRA	5'-(6-carboxytetramethylrhodamine)
AEEA	8-amino-3,6-dioxaoctanoic acid linker

In the figures the following is shown:

Figure 1 is a schematic drawing of a preferred embodiment of the assay principle of the present invention.

Figure 2 is a schematic diagram showing the binding of the polyclonal JNK antibody to TAMRA-labelled P1\*°-peptide; as a control, no binding is measured for TAMRA-labelled P1°-peptide.

Figure 3 is a schematic diagram showing the competition of the binding of the polyclonal JNK antibody to the TAMRA-labelled P1\*°-peptide using mono-phosphorylated P1°- and P1\*-peptides and double-phosphorylated P1\*°-peptide (determination of the IC<sub>50</sub> for the P1\*°-peptide competitor).

Figure 4 is a schematic diagram showing the competition of the binding of the polyclonal JNK antibody to the TAMRA-labelled P1\*°-peptide in presence of 100 µM P1°-peptide (substrate) using P1\*°-peptide (determination

of the IC<sub>50</sub> for the P1°-peptide competitor under MKK7 kinase assay conditions).

Figure 5 is a schematic diagram showing the phosphorylation of P1°-peptide substrate by MKK7 kinase at different P1°-peptide concentrations (determination of the K<sub>m</sub> for P1°-peptide).

Figure 6 is a schematic diagram showing the phosphorylation of P1°-peptide substrate by MKK7 kinase at different ATP concentrations (determination of the K<sub>m</sub> for ATP).

Figure 7 is a schematic diagram showing the inhibition of the MKK7 kinase-dependent phosphorylation of P1°-peptide substrate by Staurosporine (determination of the IC<sub>50</sub> for Staurosporine).

According to the invention, a protein or peptide comprising the sequence motif -Z-X-Y- or -Y-X-Z-, wherein Z = threonine or serine; X = a sequence of preferably between 1 and 1000 amino acids which may be the same or different; Y = tyrosine, threonine or serine, is used as a substrate for the threonine or serine kinase. According to the present invention said protein or peptide is pre-phosphorylated at the Y position. It has been shown that the proteins and peptides being pre-phosphorylated at the Y residue can be successfully used as synthetic substrates for threonine or serine kinases.

In the sequence motif, any amino acid or sequence of amino acids (X) can be inserted between Z and Y. The number of amino acids is preferably in the range of 1 to 1000 amino acids. A range of 1 to 1000 is preferred to include both linear and conformational antibody epitopes. X is particularly at least one amino acid, any other short amino acid sequences having at

least two amino acids, such as oligopeptides, being also included. Preferably, X is proline or glutamate or glycine.

The antibody used is usually a monoclonal or polyclonal antibody.

It has been shown that a particularly preferred antibody is a polyclonal antibody specific for bis-phosphorylated, in particular activated JNK. Such antibodies are commercially available.

It has been revealed that the antibody specifically recognizes a phosphorylated threonine or serine residue at the Z position within both a synthetic substrate peptide or bis-phosphorylated, in particular activated JNK.

The immunoassay according to the present invention is amenable to be carried out in a homogeneous assay format (i.e. "mix, incubate, and read"). This assay format is very advantageous because it is suitable for both high throughput screening (HTS) of potential drugs and secondary assays.

The immunoassay of the present invention may be performed as a direct binding immunoassay, preferably a homogeneous direct binding immunoassay.

In the direct binding immunoassay, a labelled peptide/protein or a labelled antibody is used. The labelling may be carried out according to conventional standard techniques. Preferably, the peptide/protein or antibody is labelled using a luminescent or a radioactive tag or by using specific labelling molecules such as a reporter enzyme or an affinity ligand.

The assay of the present invention may also be performed as a competition immunoassay, preferably a homogeneous indirect binding immunoassay.

In this indirect binding immunoassay, a labelled double-phosphorylated ligand is added to compete with the double-phosphorylated peptide or protein for binding to the antibody. The ligand is preferably labelled using a luminescent or a radioactive tag or by using specific labelling molecules such as a reporter enzyme or an affinity ligand.

In general, fluorescence detection offers a preferred alternative to the use of radiotracers, as fluorescence not only offers detection limits comparable to those of radioactivity but also eliminates the cost of radioactive waste disposal.

In case of using a protein as a substrate containing the above motif, the JNK protein is preferably used, which is the c-Jun N-terminal kinase. JNK kinase is also known in the literature as the stress-activated protein kinase 1 (SAPK1).

When it is more convenient to use a peptide substrate, the peptide sequence is preferably selected from the active-site loop, e.g. for MKK7 from the JNK1/2/3 active site. For instance, said peptide for MKK7 comprises or is composed of the amino acid sequence H-Lys-Phe-Met-Met-Thr-Pro-pTyr-Val-Val-Thr-Arg-NH<sub>2</sub>, wherein p means phosphorylated.

When the incubation of the protein or peptide is carried out in the presence of a threonine kinase, the threonine kinase is preferably a mitogen-activated protein kinase kinase (MKK), alternatively called stress activated protein kinase (SKK). More particularly, the kinase is MKK7/SKK4.

According to one embodiment of the process of the present invention, an antibody is added preferably at the start of the reaction having a specificity to the bis-phosphorylated sequence, preferably to phosphorylated threonine or serine. During the enzyme reaction any double phosphorylated product formed is bound by the antibody. Then, at the end of the enzyme reaction, a labelled, double phosphorylated ligand is added, either with or without the concomitant addition of a reagent to stop the reaction, to compete with the double phosphorylated protein or peptide for binding to the antibody. This indirect assay principle is based on the fact that if the substrate becomes double phosphorylated by the kinase such as MKK7, it will compete with the labelled, double phosphorylated peptide-antibody complex. This strategy has the advantage of using non-labelled substrates and a fixed antigen-antibody complex that gives the read-out.

Usually, the double phosphorylated ligand is labelled by common techniques, using a luminescent or a radioactive tag or by molecules such as a reporter enzyme or an affinity ligand. Preferably, the ligand is labelled by a fluorescent dye. Particularly, the ligand comprises or is composed of the sequence 5-TAMRA-AEEA-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH<sub>2</sub>.

In Fig. 1 the indirect assay principle is illustratively shown. The P1° substrate having the amino acid sequence H-Lys-Phe-Met-Met-Thr-Pro-pTyr-Val-Val-Thr-Arg-NH<sub>2</sub> (p means phosphorylated) becomes phosphorylated at the threonine residue in the presence of ATP and the MKK7 kinase. This double-phosphorylated peptide (ligand) competes with the labelled TAMRA-P1\*° peptide having the sequence 5-TAMRA-AEEA-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH<sub>2</sub> for binding to the antibody.

In a preferred embodiment, the assay may be conveniently performed as a fluorescence immunoassay, in particular fluorescence polarization (FP) immunoassay. However, other fluorescence techniques such as fluorescence correlation spectroscopy (FCS), fluorescence intensity distribution analysis (FIDA), fluorescence quenching (FQ) or fluorescence resonance energy transfer (FRET) might be applied.

According to the invention a kit for detecting threonine or serine kinase activity is provided. The kit comprises preferably the following components:

1. a threonine or serine kinase such as natural or recombinant enzyme;
2. a substrate as outlined above, e.g. in form of a monophosphorylated-peptide or mono-phosphorylated protein;
3. an antibody as outlined above;
4. reaction buffers including e.g. either  $MnCl_2$  or  $MgCl_2$ , and a phosphate donor such as ATP;
5. reaction vials; and
6. protocol

It is preferred that the kit includes a substrate and an antibody as defined above and optionally also reaction buffers, vials and protocols. The user of the kit may have the option to choose an appropriate kinase himself. In a further embodiment, the kit might also include a specific threonine or serine kinase.

The kit preferably further comprises a labelled (in particular luminescently labelled) ligand, which ligand comprises a sequence motif

-Z-X-Y- or -Y-X-Z-

wherein Z = threonine or serine

X = a sequence of preferably between 1 and 1000 amino acids which may be the same or different

Y = tyrosine, threonine or serine

This ligand acts as a competitor for performing the assay according to the present invention, said competitor being pre-phosphorylated at the Z and Y positions.

It has been revealed that the commercially available polyclonal anti-phospho-kinase antibodies are particularly useful in the assay of the present invention. As can be seen in Fig. 2 (ref. Example 1), the polyclonal phospho-JNK antibody detects all three isoforms of the JNK proteins only when activated by dual phosphorylation at threonine<sub>183</sub> and tyrosine<sub>185</sub>. The polarization values dramatically increase when using the double-phosphorylated peptide substrate P1\*° in contrast to mono-phosphorylated labelled peptide P1° (sequence see above).

In Fig. 3 (ref. Example 2) the binding of the same polyclonal antibody to TAMRA-labelled peptide P1\*° (5 nM) in competition with the peptides P1° (mono-phosphorylated, sequence see above), peptide P1\* (mono-phosphorylated having the sequence H-Lys-Phe-Met-Met-pThr-Pro-Tyr-Val-Val-Thr-Arg-NH<sub>2</sub>) or peptide P1\*° (double phosphorylated, sequence see above) is presented. As can be deduced from the complex formation, only bis-phosphorylated peptide P1\*° is able to compete effectively with the TAMRA-labelled peptide P1\*° for binding to the antibody while the other mono-phosphorylated peptides displace less than 50% of the bound ligand even at high concentrations (up to 1 µM).

In Fig. 4 (ref. Example 3) the binding of the same polyclonal antibody to TAMRA-labelled peptide P1\*° (5 nM) is displaced by bis-phosphorylated competitor peptide in presence of P1° peptide substrate (100 µM). These conditions reflect the

concentration at which P1° peptide is used as a substrate for the MKK7 kinase. As can be seen from the result, the presence of mono-phosphorylated P1° peptide does not reduce the dynamic range of the described kinase assay.

In Fig. 5 (ref. Example 4) the rate of phosphorylation of P1° peptide substrate by MKK7 kinase is determined at various P1° peptide concentrations. Efficient phosphorylation of P1° peptide is measured. The formed double-phosphorylated P1\*° peptide product can be detected as it competes with the TAMRA-labelled P1\*° peptide for the binding to the same polyclonal phospho-JNK antibody. As a results, a drop of the fluorescence polarization is detected which is inversely proportional to MKK7 kinase activity. From the detected signals, the Michaelis-Menten constant (Km), reflecting the half-maximal phosphorylation rate, was determined for P1° peptide.

In Fig. 6 (ref. Example 5) the rate of phosphorylation of P1° peptide substrate by MKK7 kinase is determined at different ATP concentrations. Efficient phosphorylation of P1° peptide is dependent on the optimal ATP concentration. The formation of the bis-phosphorylated P1\*° peptide product is detected using the same competition assay as described in Fig 5. From the detected fluorescence polarization signals, the Michaelis-Menten constant (Km), reflecting the half-maximal phosphorylation rate, was determined for ATP.

In Fig. 7 (ref. Example 6) the inhibition of the phosphorylation of P1° peptide substrate by MKK7 kinase is determined for the kinase inhibitor staurosporine. The inhibition of MKK7 kinase is detected using the same competition assay as described in Fig 5. As a result, no competition of the TAMRA-labelled P1\*° peptide from the same polyclonal phospho-JNK antibody is detected at high



Staurosporine concentrations. The half-maximal inhibitory concentration (IC<sub>50</sub>) was calculated for Staurosporine.

The following examples illustrate the assay of the present invention. The experiments described hereinafter show the feasibility to monitor the phosphorylating activity of serine/threonine kinases in a homogeneous assay format amenable to high throughput screening. The experiments are based on the finding that a modification - phosphorylation at the Y position - of the substrate in spacial proximity to the Z-site of phosphorylation not only enhances the affinity of the phosphorylated product to the detection antibody but also results in a high specificity for the phosphorylated Z position. Besides having the advantage of affinity enhancement of the antibody, the modification of the substrate according to the present invention turns out to have an unexpected positive effect on the kinetics of the kinase reaction as well.

#### Example 1:

##### Measurement of the binding affinity (K<sub>D</sub>) of antibody NEB #9251:

This polyclonal antibody detects all three isoforms of the SAPK1/JNK proteins only when they are activated by dual phosphorylation at threonine<sub>183</sub>/tyrosine<sub>185</sub>. Binding of polyclonal phospho-JNK antibody (at a dilution of 1:20) from NEB to TAMRA-labelled P1°- and P1\*° peptides (each 5 nM) was measured by fluorescence polarization.

Affinity of polyclonal phospho-JNK antibody for peptide P1\*°-TAMRA: K<sub>D</sub> = 2.6 nM

The results of this experiment are illustrated in Fig. 2.

Example 2:Determination of IC<sub>50</sub> for Peptide P1°:

Competition of NEB antibody-P1\*°-TAMRA complex with P1\*° peptide was measured by fluorescence correlation spectroscopy: Binding of polyclonal phospho-SAPK1/JNK antibody from NEB (1:20 diluted) to TAMRA-labelled peptide P1\*° (5 nM) was competed with non-fluorescent, double-phosphorylated peptide P1\*°. Control peptides: mono-phosphorylated P1° and P1\*.

Peptide P1\*°: IC<sub>50</sub> = 5.0 nM ± 3.3 nM

The results of this experiment are illustrated in Fig. 3.

Example 3:Determination of IC<sub>50</sub> for Peptide P1° (under MKK7 enzyme assay conditions).

Competition of NEB antibody-P1\*°-TAMRA complex with P1\*° in presence of P1° substrate peptide (reflecting MKK7 assay conditions) was measured by fluorescence polarization: Binding of polyclonal phospho-JNK antibody from NEB #9251 (at a dilution of 1:20) to TAMRA-labelled peptide P1\*° (5 nM), competition with P1\*° peptide (0.1, 0.5, 2, 5, 20, 50, 200, 2000 nM) in Hepes buffer, MgCl<sub>2</sub> 10 mM, ATP 20 µM, Pluronic 0.1%, P1° substrate peptide 100 µM.

Peptide P1\*°: IC<sub>50</sub> = 35.1 nM ± 10.6 nM

The results of this experiment are illustrated in Fig. 4.

Example 4:

Determination of  $K_m$  for peptide  $P1^\circ$  (Read-out: fluorescence polarization):

Assay conditions: MKK7 kinase (80 nM),  $P1^\circ$  peptide (0, 10, 30, 70, 100, 200, 500  $\mu$ M), ATP (100  $\mu$ M), NEB antibody #9251 (1:20) diluted and  $P1^{*\circ}$  peptide-TAMRA (5 nM) at RT (room temperature).

$$K_m = 94 \text{ nM} \pm 59 \text{ nM}, \quad V_{\max} = 94.6 \text{ nM/min} \pm 0.03 \text{ nM/min}$$

The results of this experiment are illustrated in Fig. 5.

Example 5:

Determination of  $K_m$  for ATP (Read-out: fluorescence polarization):

Assay conditions: MKK7 (80 nM),  $P1^\circ$  peptide (100  $\mu$ M), ATP (0, 1, 5, 10, 20, 50, 100, 200, 500  $\mu$ M), incubation time to 2h at RT, polyclonal active-JNK antibody from NEB #9251 (1:20 dilution) and  $P1^{*\circ}$  peptide-TAMRA at (5 nM).

$$K_m = 17.3 \text{ nM} \pm 18.1 \text{ nM}, \quad V_{\max} = 0.28 \text{ mP/min} \pm 0.07 \text{ mP/min}$$

The results of this experiment are illustrated in Fig. 6.

Example 6:

Inhibition of MKK7 activity with Staurosporine (Read-out: fluorescence polarization):

Assay conditions: MKK7 (0.3  $\mu$ M),  $P1^\circ$  peptide (100  $\mu$ M), ATP (10  $\mu$ M), Staurosporine (0, 0.05, 0.2, 1, 2, 5, 10  $\mu$ M), polyclonal active-JNK antibody from NEB #9251 (1:20 dilution) and  $P1^{*\circ}$  peptide-TAMRA at (5 nM).

$IC_{50} = 63.3 \text{ nM} \pm 10.2 \text{ nM}$

The results of this experiment are illustrated in Fig. 7.

Example 7:

Fluorescence Polarization measurements of MKK7 activity (time course):

In this experiment, the time course has been investigated at  $P1^{\circ}$  substrate concentrations of 100  $\mu\text{M}$ . The reactions were stopped with EDTA.

The following reagents have been used (the compositions of the buffers and specifications of the reagents are explained in more detail later on):

Hepes buffer,  $\text{MgCl}_2$  10 mM, ATP 20  $\mu\text{M}$ ,  $P1^{\circ}$  peptide at 100  $\mu\text{M}$ , NEB antibody # 9251 1:20 dilution,  $P1^{\circ}$ -TAMRA 5 nM, Pluronic 0.1%, MKK7 at 0, 0.005, 0.02, 0.08, 0.2, 0.5 and 2  $\mu\text{M}$ .

After addition of MKK7, the enzyme reactions were performed in Nunc chambers at RT. The samples were continuously measured at different time points by Fluorescence polarization.

	0 h
Conjugate: $P1^{\circ}$ -Tamra	39,7
High: $P1^{\circ}$ -Tamra + NEB ab (1:20)	139,1
Low: $P1^{\circ}$ -Tamra + NEB ab (1:20) + $P1^{\circ}$ 200 nM	84,5

100 $\mu$ M P1°	0 h	0.5 h	1 h	1.5 h	3 h
MKK7: 0.0 $\mu$ M	134.7	139.1	139.7	140.2	144.8
MKK7: 0.005 $\mu$ M	131.5	137.4	136.8	136.9	138.1
MKK7: 0.02 $\mu$ M	135.4	140.3	140.9	139.7	140.0
MKK7: 0.08 $\mu$ M	133.5	137.6	135.8	128.4	115.2
MKK7: 0.2 $\mu$ M	135.3	132.7	121.9	113.8	104.7
MKK7: 0.5 $\mu$ M	135.3	125.5	115.3	108.8	106.6
MKK7: 1.0 $\mu$ M	135.7	119.6	112.2	105.3	108.4

Fluorescence Polarization (FP) values are given in mP.

Example 8:Fluorescence Polarization measurements of MKK7 activity (time course):

In this experiment the assay conditions have been optimized. The reactions were stopped with EDTA.

Two different assay strategies were investigated: first, the NEB read-out antibody was included in the enzyme reaction (STOP solution: contains only EDTA and P1\*-TAMRA); second, the NEB read-out antibody was included in the STOP solution.

The following reagents have been used (explanations later on): Hepes buffer, MgCl<sub>2</sub> (10 mM), ATP (20 µM), P1° peptide (100 µM), polyclonal antibody NEB #9251 (1:20), P1\*-TAMRA (5 nM), Pluronic (0.1%), BSA (0.01%), MKK7 at (0.04, 0.08 and 0.2 µM), EDTA (10 mM) (all final conc.).

The enzyme reactions were performed in Eppendorf reaction tubes at RT. Aliquots of 20 µl were withdrawn from the reactions at different time points and mixed with 10 µl STOP solution. The stopped reactions were incubated at RT for at least 30 min and measured by Fluorescence Polarization.

## Results:

	0 h
Conjugate: P1*-Tamra	33,2
High: P1*-Tamra + NEB ab (1:20)	145,7
Low: P1*-Tamra + NEB ab (1:20) + P1* 200 nM	71,5

NEB ab in reaction	0 h	0.5 h	1 h	1.5 h	2 h	3 h
MKK7: 0.04 $\mu$ M	150.0	128.5	125.7	112.9	109.7	78.6
MKK7: 0.08 $\mu$ M	138.5	122.5	105.9	86.4	84.5	65.0
MKK7: 0.2 $\mu$ M	137.2	101.4	83.1	78.1	72.1	59.4
NEB ab in STOP sol.						
MKK7: 0.04 $\mu$ M	147.2	141.5	140.2	135.8	134.2	138.2
MKK7: 0.08 $\mu$ M	143.3	139.1	133.6	122.1	115.8	125.0
MKK7: 0.2 $\mu$ M	148.2	130.2	114.0	102.8	99.2	119.4

Fluorescence Polarization (FP) values are given in mP.

#### Example 9:

Fluorescence Polarization measurements of MKK7 activity (time course) in Nanocarrier plates (supplier: EVOTEC BioSystems AG, 1.2  $\mu$ l volume):

#### Assay conditions (end conc.):

1. P1° substrate 100  $\mu$ M, polyclonal antibody NEB #9251 (1:20), ATP 20  $\mu$ M, MgCl 10 mM
2. MKK7 enzyme: 0, 25, 50, 75, 100, 200, 350, 500 nM
3. STOP solution: EDTA 10 mM, P1\*°-TAMRA (5 nM)

#### Stock solutions:

1. P1° substrate 125  $\mu$ M, NEB ab (1:13.3), ATP 25  $\mu$ M, MgCl 12.5 mM
2. MKK7 enzyme: 2500 nM
3. STOP solution: EDTA 60 mM, P1-TAMRA 30 nM

Solutions 1. - 3. in Hepes buffer, Pluronic 0.1%, BSA 0.01%.

It has been revealed that bis-phosphorylated-TAMRA-P1\*°-peptide (ligand) is bound by the polyclonal anti-active JNK-antibody, which is called "high" or "positive control". Bis-phosphorylated peptide P1\*° can be used as competitor, resulting in free labelled ligand called "low" or "negative control". This can be seen in Figure 8 where FP values are given in mP and the bars illustrate the time course at different enzyme concentrations.



List of reagents of the MKK7 kinase assay:**List of used JNK1-peptides:**

P1°            H-Lys-Phe-Met-Met-Thr-Pro-pTyr-Val-Val-Thr-Arg-NH2  
P1\*            H-Lys-Phe-Met-Met-pThr-Pro-Tyr-Val-Val-Thr-Arg-NH2  
P1\*°           H-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH2  
TAMRA-P1\*°    5-TAMRA-AEEA-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH2

**Ligand:**

TAMRA-P1\*°-Peptide: 5-TAMRA-AEEA-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH2

Supplier: EVOTEC BioSystems AG, solid-phase peptide synthesis  
HK-03-65-P1-13; M = 2089 g/mol; MALDI (2092.18)

1mM stock solution in 100% DMSO

The stock should be aliquoted in 10 µl aliquots and kept at -20°C.

5nM working solution.

**Competitor:**

P1\*°-Peptide: H-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH2

Supplier: EVOTEC BioSystems AG, solid-phase peptide synthesis  
HK-03-60-P1-7; M = 1532 g/mol; MALDI (1531.88)

10mM stock solution in 100% DMSO

The stock should be aliquoted in 10 µl aliquots and kept at -20°C.

200µM working solution.

**Substrate: MKK7 kinase substrate**

P1°-Peptide: H-Lys-Phe-Met-Met-Thr-Pro-pTyr-Val-Val-Thr-Arg-NH2

Supplier: EVOTEC BioSystems AG, solid-phase peptide synthesis  
HK-03-58-HF; M = 1451 g/mol; MALDI (1453.57)

10mM stock solution in 100% DMSO

The stock should be aliquoted in 10  $\mu$ l aliquots and kept at -20°C.

100 $\mu$ M working solution.

**Enzyme:**

MKK7 kinase Supplier: Upstate Biotech cat. no. 14-366, lot no. 19105 and no. 20658.

See enzyme activity specifications on the respective certificate of analysis.

Specific activity: Approximately 20 Units/mg when max. activated.

20  $\mu$ g of enzyme (9  $\mu$ M) in 50 $\mu$ l of 50 mM Tris-HCl, pH 7.5, 150 mM NaCl, 270 mM sucrose, 0.1 mM EGTA, 0.1% 2-mercaptoethanol, 0.03% Brij-35, 1 mM benzamidine, 0.2 mM PMSF.

The stock was kept at -70°C. Freezing and thawing cycles were avoided.

**Anti active SAPK1/JNK-specific antibody:**

New England Biolabs, U.S.A.: NEB #9251

Anti active JNK polyclonal antibody purified via affinity chromatography (Protein A) from rabbit serum, conc.: 0.02 mg/ml, equiv. 130 nM. Storage buffer: 10 mM Hepes pH 7.5, 150 mM NaCl, 100  $\mu$ g/ml BSA, 50 % glycerol, store at -70 °C. The stock should be aliquoted in 10  $\mu$ l aliquots and kept at -20°C.

Working solution: 1:20 dilution in 1x Assay-Buffer/0.1%

Pluronic

**Reagents and buffers:***Assay buffer:**10x HEPES-Assay-Buffer pH 7.5**500mM HEPES**1mM EGTA**100mM DTT**62.5mM NaCl*

Dissolve 770mg DTT (FLUKA cat. no. 43815; MW 154.25g/mol) [final concentration 100mM] in 30 ml of Millipore water, add 625µl of 5M NaCl<sub>2</sub> [final concentration 62.5mM], 19.02mg EGTA (Merck cat. No.1.06404; MW 380.35g/mol) [final concentration 1mM] and 5.96g HEPES (FLUKA cat. no. 54457) [final concentration 500mM] and adjust pH with 1M NaOH to pH 7.5. Top up to 50 ml with Millipore water. The buffer was filtered sterile (0.22µm) aliquoted to 1.5ml and was stored at -20°C.

*1M MgCl<sub>2</sub>:*

Dissolve 10.2 g MgCl<sub>2</sub>.6H<sub>2</sub>O (FLUKA cat. no. 63068) in 50 ml of Millipore water. Buffer was filtered (0.42µm) and can be stored at 4°C for several months.

*1% (w/v) Pluronic F-127*

Dissolve 0.5 g Pluronic (Sigma, cat. no. P-2443) in 50 ml of Millipore water. Stir gently to get a clear solution. Solution was filtered (0.42µm) and can be stored at 4°C for several months.

*1x HEPES-Assay-Buffer/0.1% Pluronic pH 7.5: (15ml):**50mM HEPES**0.1mM EGTA**10mM DTT**0.1% Pluronic*

Add 1.5 ml 1% (w/v) Pluronic F-127 in water and 1.5 ml of 10x HEPES-Assay-Buffer pH 7.5 to 12 ml of Millipore water. Stir the

mixture and check the pH value. The mixture could be stored at 4°C for 1-2 weeks.

*0.5M EDTA (50ml):*

Dissolve 9.309g EDTA (Roche Molecular Biochemicals, cat. no. 808288) in 40 ml of Millipore water and adjust pH to 8-9 with 10M NaOH in order to get a clear solution. Top up to 50 ml with Millipore water. Buffer was filtered (0.42µm) and can be stored at 4°C for several months.

*10mM ATP (15ml):*

Dissolve 9.1mg ATP (Roche Molecular Biochemicals, cat. no. 126888) in 1.5 ml 1x HEPES-Assay-Buffer/0.1% Pluronic pH 7.5. The solution was filtered (0.42µm) and can be stored at -20°C for 2 weeks.

*DMSO: 100% DMSO*

The solvent was purchased from SIGMA (cat. No. P-2650), sterile filtered.

Claims

1. A process for detecting threonine or serine kinase activity in an immunoassay comprising the following steps:

a) providing a protein or peptide comprising the sequence motif

-Z-X-Y-      or    -Y-X-Z-

wherein

Z = threonine or serine

X = a sequence of amino acids, preferably between 1 and 1000 amino acids, which may be the same or different

Y = tyrosine, threonine or serine

as a substrate for threonine or serine kinase, said protein or peptide being pre-phosphorylated at the Y position;

b) incubating the protein or peptide with a phosphate donor and a threonine or serine kinase to form a protein or peptide which is phosphorylated at positions Y and Z;

c) adding an antibody having a specificity to a peptide or protein which is phosphorylated at the Y and Z position; and

d) detecting the threonine or serine kinase activity.

2. The process according to claim 1, wherein the phosphate donor is ATP, GTP, or a synthetic cosubstrate.

3. The process according to claim 1 or 2, wherein the immunoassay is performed as a direct binding immunoassay, preferably a homogeneous direct binding immunoassay.

4. The process according to claim 3, wherein a labelled peptide or protein is used as a substrate.

5. The process according to claim 3, wherein a labelled antibody is used.
6. The process according to claim 4 or 5, wherein the peptide/protein or antibody is labelled by a luminescent tag, a radioactive marker, a reporter enzyme or an affinity ligand.
7. The process according to claim 1 or 2, wherein the immunoassay is performed as an indirect binding immunoassay, preferably a homogeneous indirect binding immunoassay.
8. The process according to claim 7, wherein a labelled ligand which is phosphorylated at its Y and Z position (bis-phosphorylated ligand) is added to compete with the protein or peptide which is phosphorylated at its Y and Z position (bis-phosphorylated protein or peptide) for binding to the antibody.
9. The process according to claim 8, wherein the bis-phosphorylated ligand is labelled by a luminescent tag, a radioactive marker, a reporter enzyme or an affinity ligand.
10. The process according to claim 9 wherein the ligand comprises Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH<sub>2</sub>, and particular is 5-Tamra-Ahx-Lys-Phe-Met-Met-pThr-Pro-pTyr-Val-Val-Thr-Arg-NH<sub>2</sub>.
11. The process according to at least one of claims 1 to 10, wherein the assay is performed as a fluorescence immunoassay, in particular a fluorescence polarization immunoassay, a fluorescence correlation spectroscopic assay, a fluorescence resonance energy transfer assay, or a fluorescence intensity distribution assay.

12. The process according to at least one of claims 1 to 11, wherein X in the sequence motif comprises proline or glutamate or glycine.
13. The process according to at least one of claims 1 to 12, wherein the protein provided is JNK1, JNK2 or JNK3 protein.
14. The process according to at least one of claims 1 to 12, wherein the peptide provided includes sequences identical to those of the JNK1, JNK2 or JNK3 active-site loop.
15. The process according to claims 1 to 12 wherein the peptide comprises the amino acid sequence H-Lys-Phe-Met-Met-Thr-Pro-pTyr-Val-Val-Thr-Arg-NH<sub>2</sub> (p means phosphorylated).
16. The process according to claim 1 to 12 wherein the peptide is composed of the amino acid sequence H-Lys-Phe-Met-Met-Thr-Pro-pTyr-Val-Val-Thr-Arg-NH<sub>2</sub> (p means phosphorylated).
17. The process according to at least one of claims 1 to 16, wherein the incubation of the protein or peptide is carried out in the presence of a threonine kinase.
18. The process according to claim 17 wherein the threonine kinase is a mitogen-activated protein kinase kinase (MKK) (also named stress activated protein kinase kinase, SKK).
19. The process according to claim 18 wherein the kinase is MKK7 (also named SKK4).
20. The process according to at least one of claims 1 to 19, wherein the antibody is a monoclonal or polyclonal antibody.
21. The process according to claim 20 wherein the antibody is a polyclonal antibody.

22. The process according to claim 21 wherein the antibody is a polyclonal antibody specific for bis-phosphorylated, in particular active JNK.

23. The process according to at least one of claims 1 to 22 wherein steps a) to d) are performed sequentially.

24. A kit for detecting threonine or serine kinase activity in an immunoassay comprising the following components:

- a substrate as defined in claim 1;
- an antibody as defined in claim 1.

25. The kit according to claim 24 further comprising a threonine or serine kinase, and/or reaction buffers including a phosphate donor, preferably ATP.

26. The kit according to claim 24 or 25 further comprising a labelled ligand, preferably luminescently labelled ligand, said ligand comprising the following sequence motif

-Z-X-Y-      or      -Y-X-Z-

wherein

Z = threonine or serine

X = a sequence of amino acids, preferably between 1 and 1000 amino acids, which may be the same or different

Y = tyrosine, threonine or serine

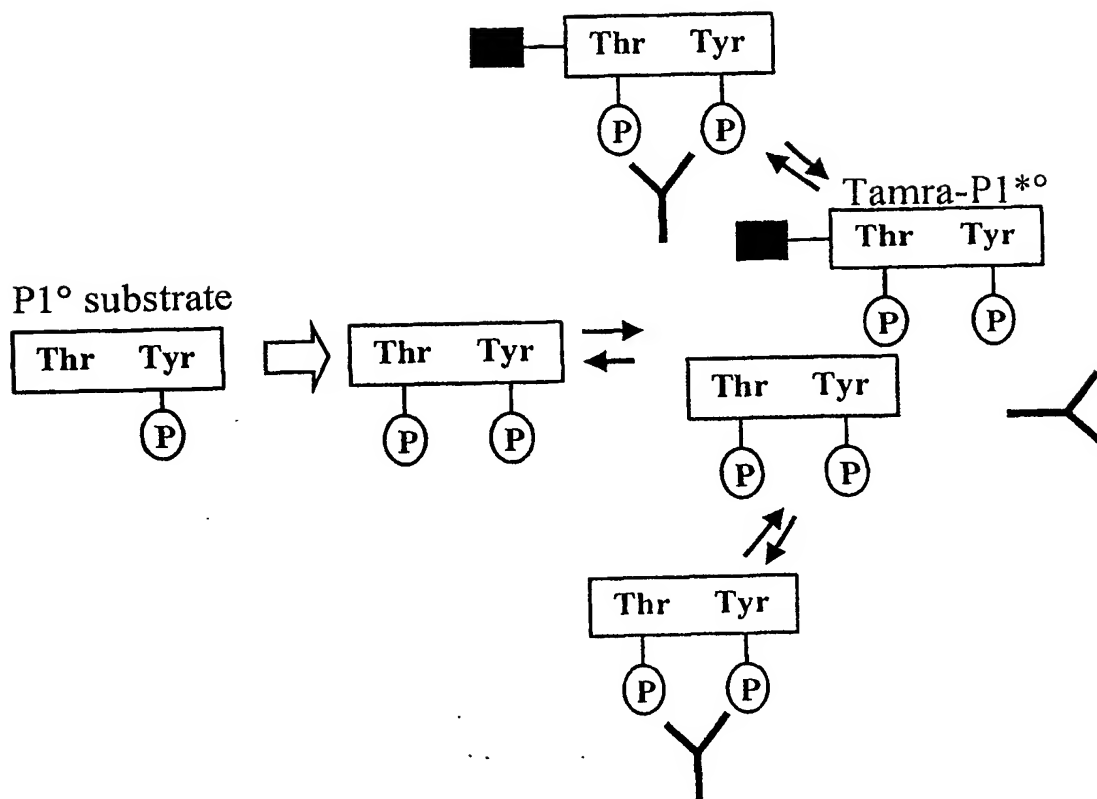
said protein or peptide ligand being phosphorylated at the Z and Y positions;

27. A labelled ligand for use in a serine/threonine kinase assay comprising the sequence motif according to claim 26.



28. A use of the assay process according to at least one of the claims 1 to 23 or the kit according to claims 24 to 26 or the ligand according to claim 27 for screening modulators for threonine or serine kinase activity, in particular inhibitors for a threonine or serine kinase, or for detecting novel threonine or serine kinases.

Figure 1:



2/8

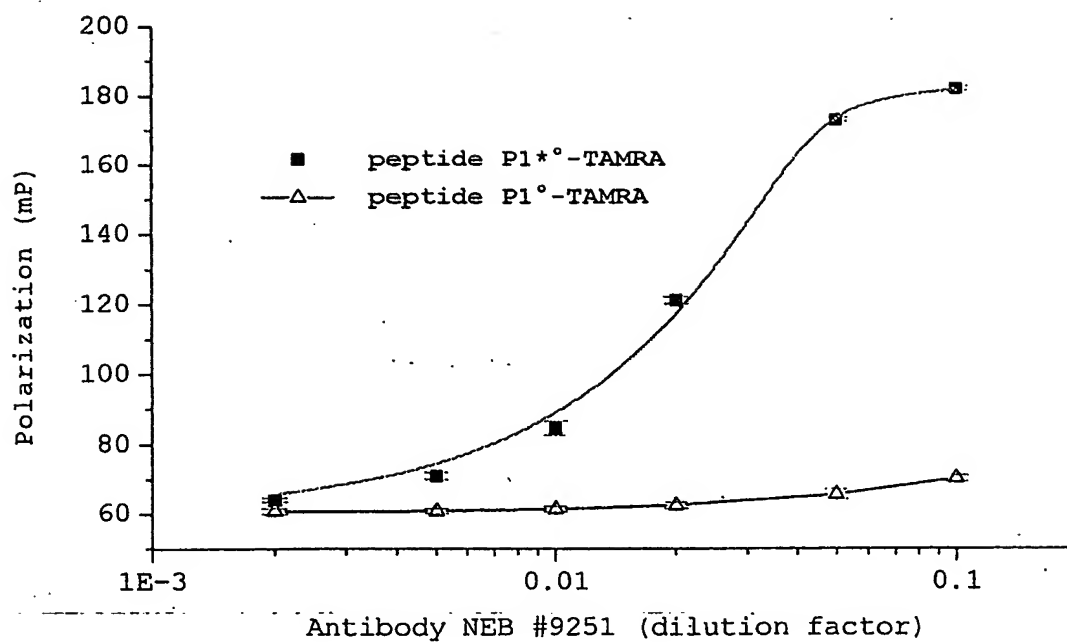
Figure 2:

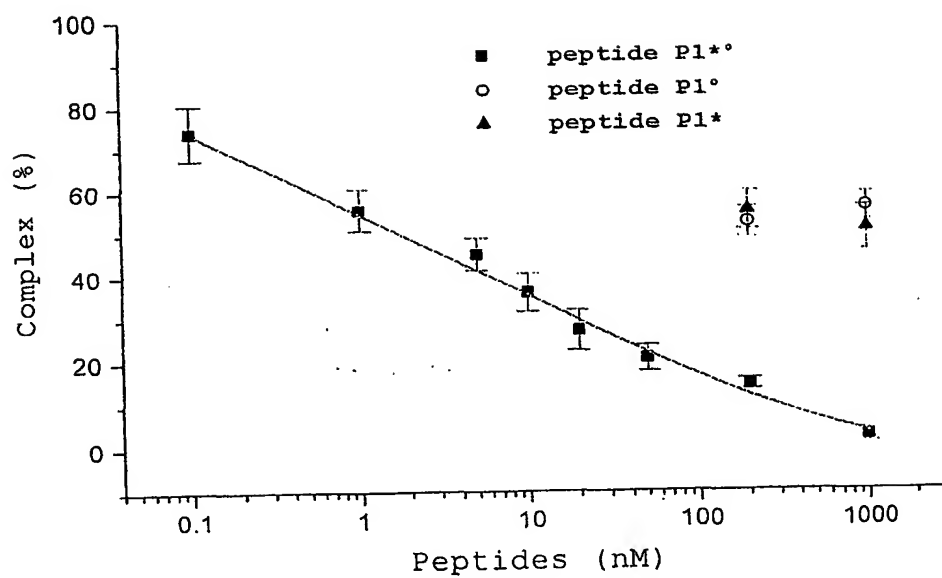
Figure 3:

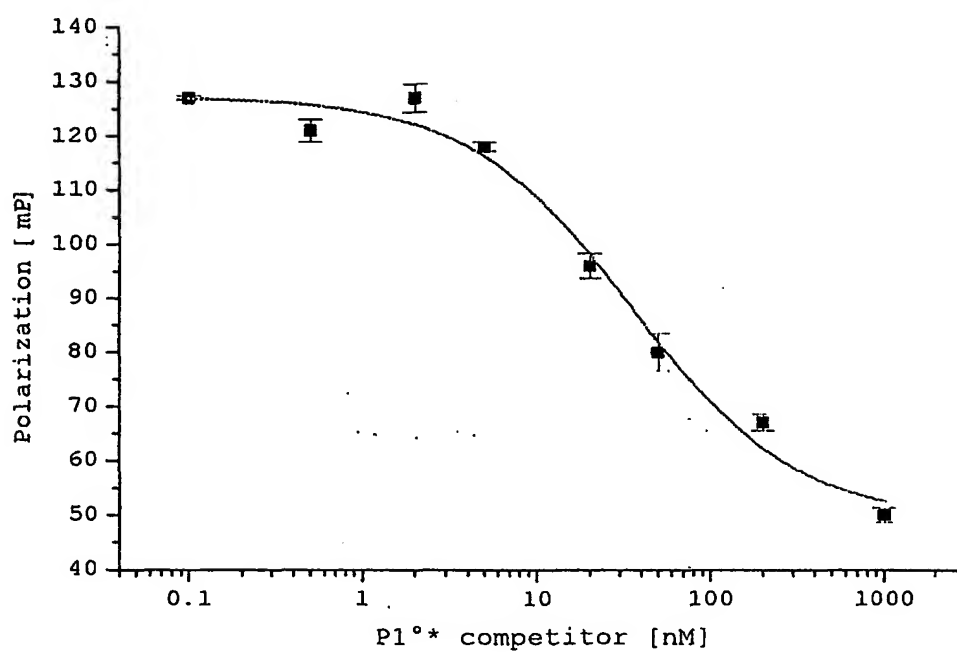
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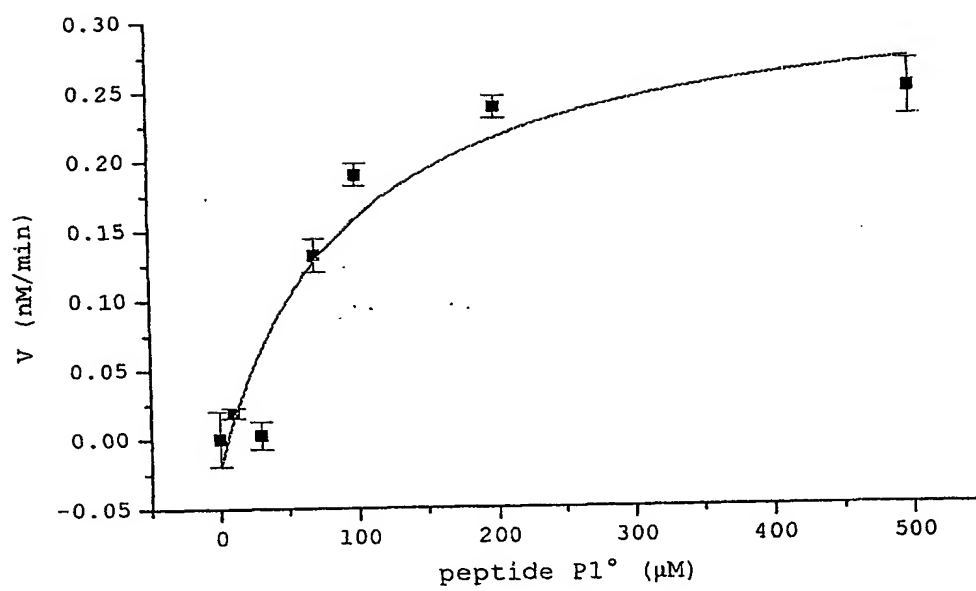
Figure 5:

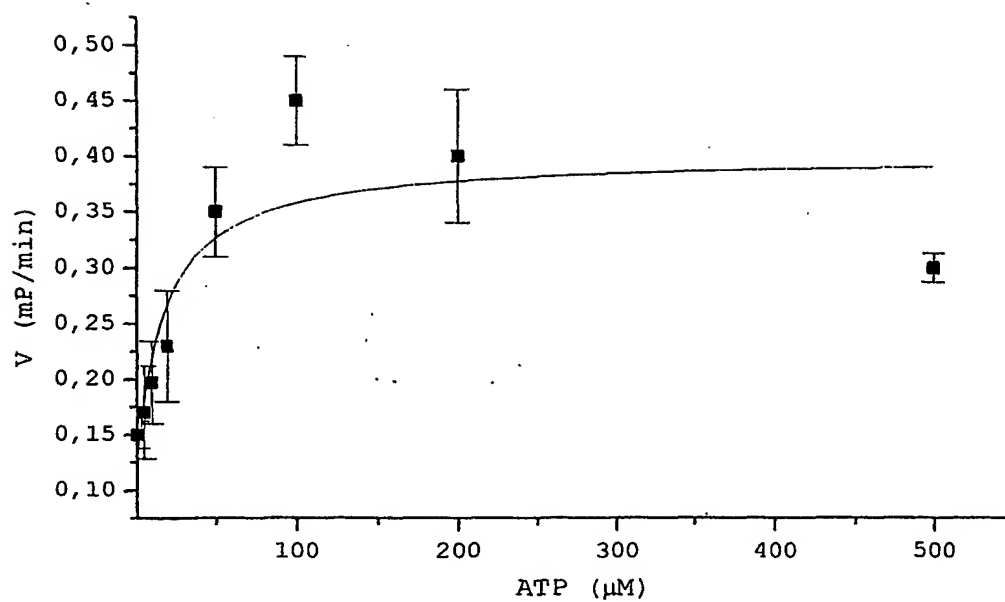
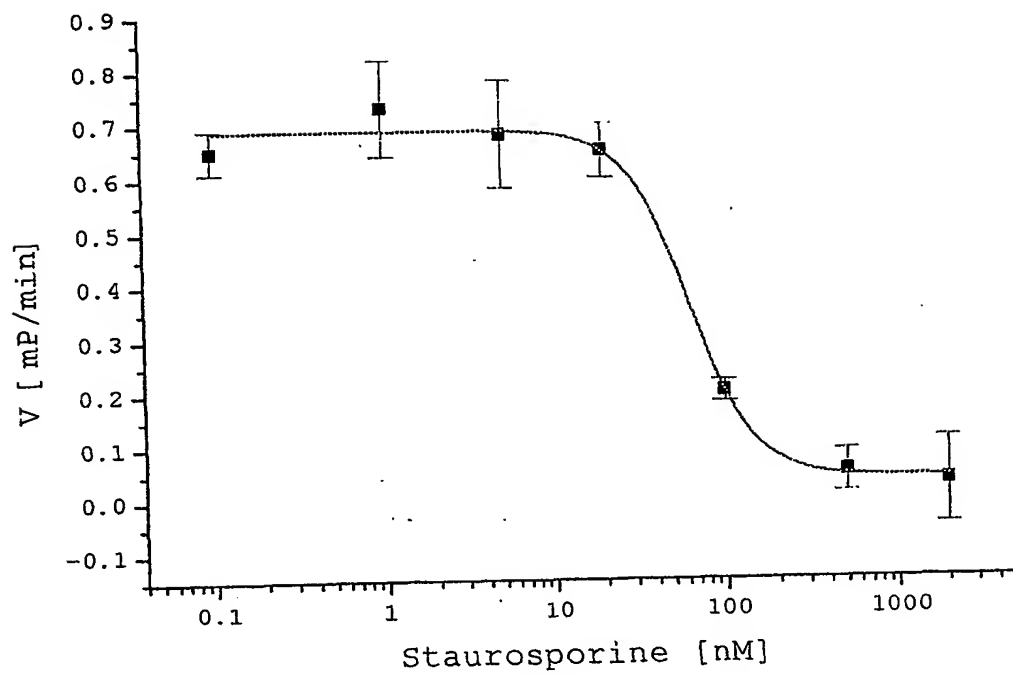
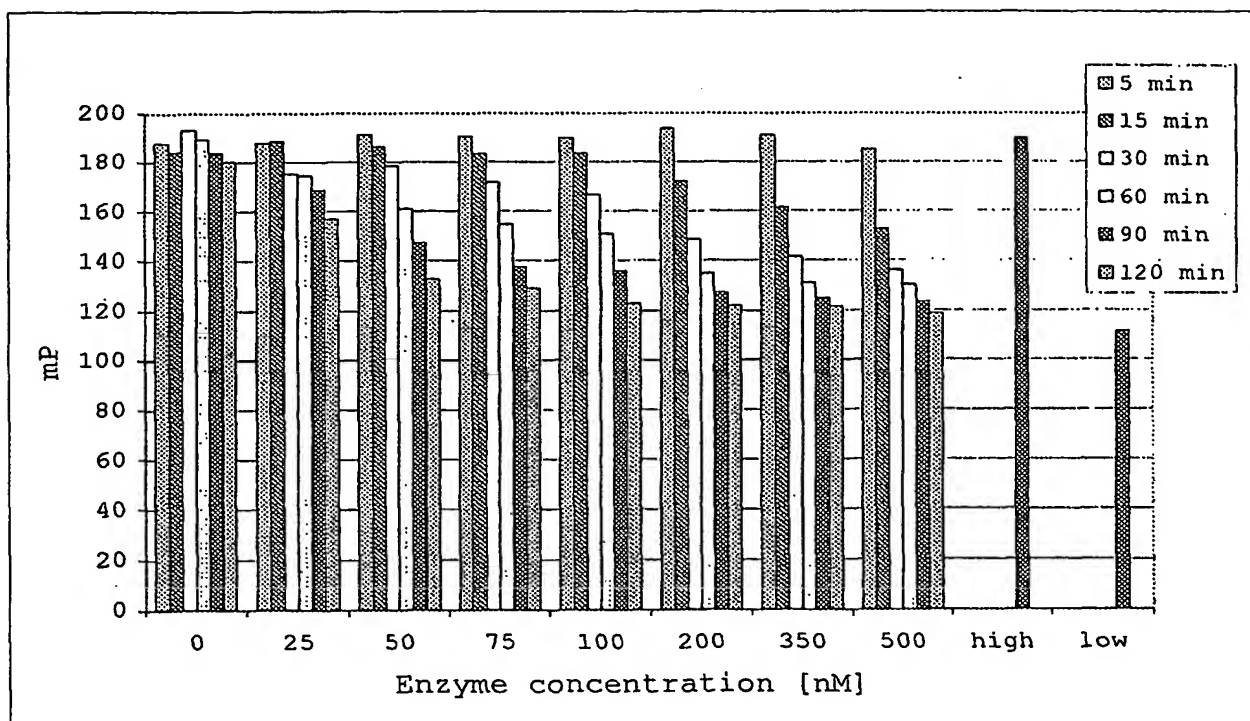
Figure 6:

Figure 7:



8/8

Figure 8:

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**21 February 2002 (21.02.2002)**

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**(71) Applicants: EVOTEC OAI AG** [DE/DE]; Schnackenburgallee 114, 22525 Hamburg (DE). **PFIZER LIMITED** [GB/GB]; Sandwich, Kent CT13 9NJ (GB).

(72) **Inventors:** KRÄMER, Joachim; c/o Evotec Biosystems AG, Schnackenburgallee 114, 22525 Hamburg (DE). MANDER, Thomas; c/o Evotec Biosystems AG, Schnackenburgallee 114, 22525 Hamburg (DE). BETHELL, Richard; c/o Pfizer Limited, Sandwich,

**Kent CT13 9NJ (GB).** **BENSON, Neil;** c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB). **BOYD, Helen;** c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB). **GREENGRASS, Pam;** c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB). **KINLOCH, Ross;** c/o Pfizer Limited, Sandwich, Kent CT13 9NJ (GB).

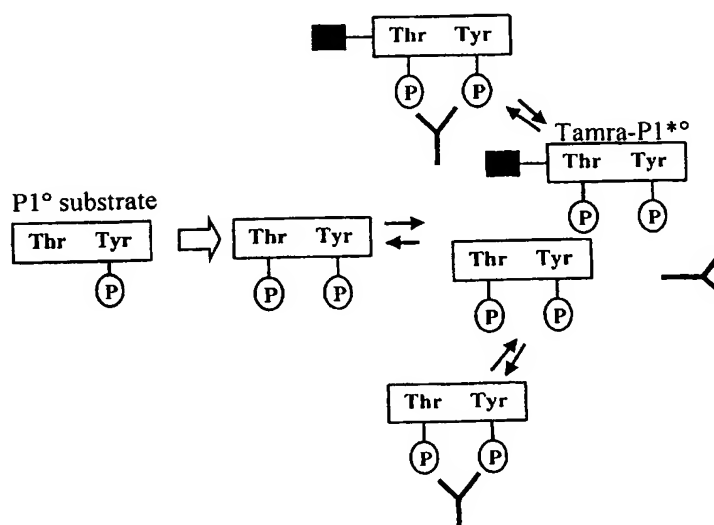
(74) Agent: **DRAUDT, Jutta**; v. Bezold & Sozien, Akademiestrasse 7, 80799 München (DE).

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*[Continued on next page]*

**(54) Title:** PROCESS FOR DETECTING SERINE/THREONINE KINASE ACTIVITY



**(57) Abstract:** Detection of threonine or serine kinase activity in an immunoassay involves incubating a labelled monophosphorylated protein or peptide with a phosphate donor and a threonine or serine kinase to form bisphosphorylated protein or peptide and adding an antibody having a specificity to the bisphosphorylated form. The immunoassay is useful for detecting/screening modulators and inhibitors for serine or threonine kinase activity (claimed), and to screen compound libraries in order to locate molecules. The phosphorylation at a position of the substrate in a special proximity to an other site of phosphorylation not only enhances the affinity of the phosphorylated product to the detection antibody but also results in a high specificity for the other phosphorylated position and has a positive effect on the kinetic of the kinase reaction.

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CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD,  
TG).

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## INTERNATIONAL SEARCH REPORT

International Application No  
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IPC 7 C12Q1/48 G01N33/68

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 C12Q G01N C12N C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)  
BIOSIS, EPO-Internal, WPI Data, PAJ, MEDLINE, EMBASE, COMPENDEX, INSPEC

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KHOKHLATCHEV ANDREI ET AL: "Reconstitution of mitogen-activated protein kinase phosphorylation cascades in bacteria: Efficient synthesis of active protein kinase." JOURNAL OF BIOLOGICAL CHEMISTRY, vol. 272, no. 17, 1997, pages 11057-11062, XP002163437 ISSN: 0021-9258 abstract; figure 2	1, 2, 12, 17, 20, 21, 23-25, 28
Y	--- -/--	1-28

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NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MARTIN HUMBERTO ET AL: "Regulatory mechanisms for modulation of signaling through the cell integrity Sit2-mediated pathway in <i>Saccharomyces cerevisiae</i> ." JOURNAL OF BIOLOGICAL CHEMISTRY, vol. 275, no. 2, 14 January 2000 (2000-01-14), pages 1511-1519, XP002225502 ISSN: 0021-9258 abstract page 1512, left-hand column, line 4 - line 13 figure 3	1, 18, 20-24, 28
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Y	LAWLER SEAN ET AL: "Synergistic activation of SAPK1/JNK1 by two MAP kinase kinases in vitro." CURRENT BIOLOGY, vol. 8, no. 25, 17 December 1998 (1998-12-17), pages 1387-1390, XP000991273 ISSN: 0960-9822 cited in the application the whole document	1-28
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International Application No

PCT/EP 01/09186

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>HOFFMANN RALF ET AL: "Phosphorylation of the C-terminal sites of human p53 reduces non-sequence-specific DNA binding as modeled with synthetic peptides."            BIOCHEMISTRY,            vol. 37, no. 39, pages 13755-13764,            XP002225711            ISSN: 0006-2960            abstract            page 13756, left-hand column, line 10            -right-hand column, line 3; table 1</p>	27
Y	<p>DATABASE BIOSIS 'Online!            BIOSCIENCES INFORMATION SERVICE,            PHILADELPHIA, PA, US;            August 1999 (1999-08)            BARANCIK MIROSLAV ET AL: "Okadaic acid and anisomycin are protective and stimulate the SAPK/JNK pathway."            Database accession no. PREV199900492152            XP002225692            abstract            &amp; JOURNAL OF CARDIOVASCULAR PHARMACOLOGY,            vol. 34, no. 2, August 1999 (1999-08),            pages 182-190,            ISSN: 0160-2446</p>	1-28
Y	<p>WO 99 29894 A (EPPS DENNIS E ;UPJOHN CO (US); MARSCHKE CHARLES K (US))            17 June 1999 (1999-06-17)            the whole document</p>	1-28
T	<p>FLEMING YVONNE ET AL: "Synergistic activation of stress-activated protein kinase 1/c-Jun N-terminal kinase (SAPK1/JNK) isoforms by mitogen-activated protein kinase kinase 4 (MKK4) and MKK7."            BIOCHEMICAL JOURNAL,            vol. 352, no. 1,            15 November 2000 (2000-11-15), pages            145-154, XP000990277            ISSN: 0264-6021            cited in the application            the whole document</p>	

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Information on patent family members

International Application No

PCT/EP 01/09186

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